Northwestern University
Department of Physics and Astronomy
Evanston, Illinois 60208-3112

This report covers the period of October 15, 1995 to October 14, 1996.

1. STAFF

Astrophysics faculty are Lee Samuel Finn, David M. Meyer, Guy Miller, Giles Novak, Ronald E. Taam, Melville P. Ulmer and Farhad Yusef-Zadeh. Research Professors and Post Doctoral Fellows (and their Ph.D. granting institutions) are: Jessie Dotson (Univ. of Chicago), Diane Dutkevitch (Univ. of Massachusetts), Larry Kidder (Washington Univ., St. Louis), Steven M. Matz (Univ. of New Hampshire), Rachel Pildis (to arrive Nov. 10; Univ. of Michigan), William R. Purcell (Northwestern Univ.), A. Katherine Romer (to leave Dec. 31; Univ. of Edinburgh), Eric L. Sandquist (Univ. of California, Santa Cruz), and Q. Daniel Wang (Columbia Univ.). Deborah Brown continues as a full-time lecturer. Professor Emeritus Wm. Buscombe continues to work on his star catalog. Graduate students are Anne Collins, Hyong Lee, Tom Renbarger, and John Watson. Robert Hood is a programmer working on the Gamma Ray Observatory project along with secretary Catherine Prullage. Melville P. Ulmer continues as Director. Scott Grossman, James Terman, and David Grabelsky have left to take jobs in industry.

The University has approved plans to refurbish and upgrade the 18-inch reflector in Dearborn Observatory. Refurbishment is planned to take place in earnest in the spring of 1997.

2. RESEARCH

2.1 Accretion Disks

With graduate student J. A. Milsom, R. Taam has studied the time dependent evolution of inertial acoustic waves in the inner region of the disk surrounding black holes. The vertically integrated solutions reveal qualitatively distinct behavior in three regimes. In particular, for sufficiently high mass accretion rates the disk is stable to inertial acoustic oscillations; at intermediate rates a global oscillation occurs at the maximum epicyclic frequency, and local oscillations at the local epicyclic frequencies are also present. At low accretion rates the disk exhibits local oscillations at all radii with no global oscillation. The disk luminosity power spectra are characterized by power law slopes of between -1.95 and -0.8 with the flattest spectra corresponding to the lowest accretion rates. In each regime the luminosity oscillation amplitudes are largest for large viscosities (rms variations always about 1%) and the oscillations vanish if the viscosity is sufficiently small. Constant viscosity models and alpha viscosity models were used and these yield qualitatively similar results. The locations of the transitions between these three regimes in terms of the Eddington accretion rate are approximately independent of the mass of the black hole. Unless disk coronae or multi-dimensional effects reduce the amplitude of these oscillations, observations of these oscillations should be possible with RXTE (Rossi X-ray Timing Explorer).

In a separate study, Milsom and Taam have performed radiation hydrodynamic simulations of two-dimensional optically thick black hole accretion disks under conditions of varying mass accretion rate and kinematic viscosity. Specifically, the effects of inertial acoustic oscillations and convection on disk structure and observable properties have been studied. It is found that global oscillations with rms amplitudes of about 0.3% can be present at the maximum epicyclic frequency in the disk. These oscillations are favored for low accretion rates and large viscosities. Local oscillations at the local epicyclic frequencies are always present with rms amplitudes of about 0.2%. These oscillations yield power spectra with spectral slopes of -0.98 and -1.33. Qualitatively similar behavior is found for disks described by an alpha law or a constant viscosity. Oscillations may be present for a restricted range of parameters for any viscosity law in which the shear viscosity increases upon compression, and they may be detectable with the RXTE. It is also found that for sufficiently high mass accretion rates, convection dominates the transfer of energy in the disk. The convection cells generally stretch from the midplane to the disk surface at lower accretion rates while the cells appear on varying length scales at high accretion rates.

In collaboration with M. A. Abramowicz (Goteborg University), I. V. Igumenschchev (Goteborg University), and X. Chen (NU), Taam has studied the morphology of adiabatic accretion flows with small non-zero specific angular momentum in the axisymmetric and nonviscous limit. For an initial state characterized by a Bondi flow with the specific angular momentum distributed with respect to polar angle, a traveling shock wave forms which propagates more rapidly in the equatorial plane than in the plane perpendicular to it, resulting in the formation of a hot torus. In cases where the incoming flow is restricted to lie near the equatorial plane, a strong wind forms directed away from this plane with the tendency for the formation of a nonsteady shock structure. As the height of the incoming flow is increased, it is found that the resultant wind weakens. The parameter regime characterized by a traveling shock and a nearly standing shock structure is delineated.

2.2 Accretion Flows

G. S. Miller's research is primarily concerned with compact objects — neutron stars, black holes, and white dwarfs. Although it has long been known that many cosmic X-ray sources are binary systems, and that the X-rays are produced when gas from a companion star is accreted by a neutron star or black hole, the structure of the accretion flow and the mechanisms by which the gravitational potential energy of the inflowing gas is converted to radiation remain understood only in broad outline. Part of this work has been devoted to comparing models for the production of X-ray spectra in accreting systems with flow models arrived at through studies of X-ray variability (Psaltis, Lamb, & Miller 1995). Other research has included a study of the disk/magnetosphere interaction in the bursting X-ray pulsar GRO J1744−28, based on observations of the variations of its pulse profile during X-ray outbursts (Miller 1996).

New observations offer an opportunity to substantially deepen our understanding of accreting systems, and have created a pressing need for theoretical investigations of temporal variability in accretion flows. The RXTE satellite is a new and powerful tool that is revolutionizing studies of rapid X-ray variability. Its large proportional counter enables it to collect and record X-ray photons at unprecedentedly high rates, so that it can be used to study variations at higher frequencies and in greater detail than ever before. The brightest X-ray sources provide the best data, and so it is natural to direct theoretical efforts toward modeling the most rapidly accreting galactic X-ray binaries, which include the brightest objects in the X-ray sky. The gas flows in these rapidly accreting systems are influenced not only by the tremendous gravity of the accreting neutron star or black hole, but also by the great force applied to the gas by the escaping radiation. These systems have luminosities close to or exceeding the Eddington critical luminosity, the luminosity at which radiation forces can counterbalance gravity.

Two projects nearing completion are devoted to the study of the structure and natural modes of variability of radiation-dominated (near-critical) astrophysical flows. In the first, G. S. Miller and M.-G. Park are examining time-dependent, three-dimensional perturbations of accretion by a neutron star close to its Eddington limit. Their treatment assumes a Schwarzschild geometry for the spacetime outside the neutron star and is fully general relativistic. At all the accretion rates studied, feedback between the production of radiation and the supply of gas by the flow to the radiation producing regions promotes the existence of weakly damped global modes, each of which is associated with a characteristic oscillation about steady flow. This confirms results they had obtained for Newtonian flows (Miller & Park 1995). The feedback mechanism is very general, implying that radiation hydrodynamic oscillations may be a universal feature of rapidly accreting systems. The oscillatory modes are accompanied by characteristic variations in the radiation output of the accretion flow. These variations strongly resemble the QPO found in low-mass X-ray binaries when they are on their normal and flaring spectral branches, suggesting that radiation hydrodynamic modes may already have been observed. A new result is that at sufficiently high luminosities, the flows become unstable to nonradial (aspherical) perturbations. These non-oscillatory unstable modes are not a consequence of general relativity; the earlier study failed to find them because it was designed only to find oscillatory modes. The non-oscillatory modes are associated with a convectively unstable layer in the accretion flow at moderate optical depths. They allow accretion to occur preferentially through more rapidly descending columns of gas, while the radiation produced escapes through neighboring columns in which the gas descends more slowly. It is possible that at accretion rates so high that the system exceeds the Eddington limit, these modes develop non-linearly into radiation-driven outflows.

In the second project, G. S. Miller and S. A. Grossman are investigating the dynamical behavior of radiation-driven winds, specifically winds that arise when Compton scattering transfers momentum from the radiation field to the gas. Such winds occur during strong X-ray bursts from slowly accreting neutron stars, and also may be driven from the inner regions of a black hole or neutron star accretion disk when the mass transfer rate is very high. By linearizing the dynamical radiation hydrodynamic equations around solutions for steady spherical outflow, we evaluate the response of radiation-driven winds to perturbations introduced at their inner boundaries. We find that the winds exhibit resonances that should produce quasiperiodic oscillations in their radiation output. The resonances are associated with internal waves (entropy perturbations in the flow); there appear to be no resonances associated solely with sound waves (isentropic perturbations). These resonances may cause the photospheric oscillations observed in some strong Type I X-ray bursts.

2.3 Binary Evolution

With postdoctoral fellow J. Terman (NU), Taam is investigating the common envelope phase of binary evolution for the formation of cataclysmic variable systems using the smoothed particle hydrodynamics (SPH) method. From a number of detailed numerical simulations in three dimensions, it has been found that the ejection of the common envelope is favorable for binary systems consisting of red giants of large radii and massive companions. As a major conclusion, it was shown that the survival of the system as a detached post common envelope binary is sensitive to the structure of the red giant star. In particular, a long period (greater than about 0.3 yr) system can be transformed into a short period system (less than about 1 day) provided that the common envelope exhibits a flat mass-radius profile and that sufficient orbital energy is released to unbind the envelope. The orbital separation of these systems as they emerge from the spiral-in phase is estimated, and it is found that the orbital separations increase with the core mass of the progenitor red giant star. Work is in progress with postdoctoral fellow X. Chen (NU) to study the details of the termination of the common envelope phase. Since the SPH method is inadequate for resolving the structure where sharp density gradients exist above the red giant core, a three-dimensional hydrodynamics code which includes nested subgrids to resolve the inner region of the double core is used.

With postdoctoral fellow J. Terman and undergraduate student Craig Savage, Taam is studying the origin of low mass X-ray binary systems from the helium star - main sequence binary remnants of a common envelope phase. Using a statistical Monte Carlo approach, the evolution of an initial distribution of zero age binaries is followed from the main sequence through a phase of common envelope evolution and subsequent supernova explosion of the helium star. The resultant population of low mass main sequence stars with a neutron star companion has been studied as a function of the kick velocity associated with the possible asymmetry of the supernova explosion, the efficiency of mass ejection during the common envelope phase, the minimum mass for evolution to a neutron star, and the mass distribution of the secondary components in the system. As a major result, the low mass X-ray binary population cannot be reproduced without a velocity kick in the supernova explosion. Specifically, for an average kick velocity of about 450 km/s, as inferred from the radio pulsar distribution, birthrates ranging from $\sim 3\times 10^{-6}$ to 10^{-5} yr^{-1} are indicated for efficiencies of the mass ejection process during the common envelope phase of 0.25 to 1. Work is in progress to extend these studies to investigate the constraints placed on the binary evolution from the observed properties of high mass X-ray binary systems.

2.4 Clusters of Galaxies

The high redshift ($z>0.5$) end of the X-ray cluster population is especially interesting as it can tell us so much, both about the formation of large-scale structure in the Universe, and about the physical processes that govern the cluster environment. Ulmer and Romer have been working since 3/95 on a NASA Astrophysics Data Program funded project, the SHARC Survey, to identify and analyze distant X-ray clusters. We are using the latest X-ray reduction techniques to identify clusters that were detected serendipitously in archival ROSAT PSPC pointings. The primary goals of this project are: 1) to derive the most accurate estimate to date of the high redshift X-ray cluster luminosity function, and 2) to provide the community with a large, all-sky, well understood list of distant X-ray clusters on which to base future (e.g. AXAF, GEMINI, HST) studies. Rachel Pildis (arriving Nov. 10), Anne Metevier (an NU physics senior) and colleagues at the University of Chicago and John Moores University of Liverpool (Nichol, Kron, Holden, Collins, and Burke) complete this international collaboration. The X-ray data analysis is now complete for the ≈ 500 high galactic latitude PSPC pointings at declinations greater than -10 degrees, yielding ≈ 200 extended sources. The process of differentiating distant clusters from other extended X-ray sources (blends, low redshift galaxies, and $z<0.3$ clusters) requires extensive optical follow-up. For this we rely on the 3.5m ARC telescope. Deep (to $r=23$) optical images in both r and g are being made of all the distant cluster candidates. To date, we have studied 106 candidates ($\approx 2/3$ of our sample) and have found that roughly half of them show evidence of faint (below the POSS plate limit) galaxy clustering. Multi-slit spectroscopy will be performed to confirm the source identifications and to provide cluster redshifts. Three SHARC-related papers were submitted in 1996, Nichol *et al.*, Holden *et al.* and Connolly *et al.*

2.5 Cosmology

As part of his continuing elucidation of the promise of the nascent field of gravitational-wave astronomy, L.S. Finn has recently published a detailed study of how a catalog of gravitational-wave observations of neutron star or black hole binary inspiral can be used to measure the cosmological parameters (i.e., the Hubble constant and deceleration parameter) and the spectrum of neutron star or black hole masses.

2.6 Galactic Center

A new and powerful probe to find evidence of shock activity was recently discussed by Frail, Goss & Slysh (1994). They observed numerous distinct 1720 MHz OH maser spots along the interface between the supernova remnant W28 and an adjacent molecular cloud. They suggest that the masers are being pumped collisionally behind the shock where H_2 molecules with densities and temperatures limited to 10^3-10^5 cm^{-3} and 25–200 K cause population inversion in the OH molecules (Elitzur 1976). More recent cross section calculations show a significant difference between para and ortho-H_2 rates, suggesting that the ortho/para H_2 ratio, as well as the temperature and density of H_2, can be important in collisional pumping of the 1720 MHz OH transition. The 1720 MHz transition of the OH line received comparatively little attention in the Galactic center region until Yusef-Zadeh, Uchida & Roberts (1995) used the VLA to observe the supernova remnant G $359.1-0.5$, which had been shown earlier to be surrounded by a ring of molecular gas. The ease with which such masers were detected, both along the edge of the supernova remnant, and where a non-thermal filament crossed the remnant, suggested that further searches for the OH (1720 MHz) maser line would be fruitful.

Follow-up radio observations of the Sgr A region have been carried out at the 1720 MHz transition of the OH molecule using the Very Large Array (VLA) and the Australia Telescope Compact Array (ATCA). Yusef-Zadeh and collaborators reported the detection of OH (1720 MHz) maser emission at seven different positions within a few arcminutes of the Galactic center. Most of the masers are located to the southeast of Sgr A*, at the boundary of the Sgr A East nonthermal source with the $M-0.02-0.07$ molecular cloud. One maser is located within the circumnuclear disk (CND) and another may arise as the result of an expansion of Sgr A East into molecular gas to the northwest of Sgr A*. It is likely that these maser features are excited by the interaction of shocks in the Galactic center with adjacent molecular gas. Significant circular polarization is observed toward ten distinct spectral components in the seven maser spots; if the V signal is due to Zeeman splitting, preliminary measurements of strong fields (local line-of-sight components of **B** are estimated to be between 2–4 milligauss) are inferred toward all sources. The direction of these magnetic fields is positive for all masers except for the CND maser, which is negative. The potential for these maser features as a diagnostic of shocked gas in the Galactic center is discussed.

Roberts, Yusef-Zadeh & Goss (1995) studied the kinematics of the ionized gas in the inner pc of the Galactic center. A large velocity gradient (>600 km s^{-1}) and uniformly large velocities are observed along the rims of the mini-cavity feature which is located within the inner few arcseconds of the dynamical center of the Galaxy. These observations show the kinematics of ionized gas with the highest spatial and velocity resolutions to date. They provide an estimate of the mass distribution which is consistent with a mass of $3.0\pm0.5\times10^{6}$ $M_{\odot}$ within the inner 0.13 pc of the compact radio source Sgr A*, located close to the dynamical center of the Galaxy.

A theoretical model of the formation of the mini-cavity was carried out by Melia, Coker & Yusef-Zadeh (1995). In this model, the formation of the mini-cavity is interpreted to be the result of an impact between the streamer gas and the post-bow shock gas collimated by a massive ($\sim10^{6}M_{\odot}$) black hole coincident with Sgr A*. Multi-wavelength observations, including those of He I, Brα and Brγ line emission in the inner $\sim$0.3 pc region of the Galaxy provide strong evidence for the presence of an ambient Galactic center wind with velocity $v_{w}\approx500-700$ km s^{-1} and mass loss rate $\sim3-4\times10^{-3}M_{\odot}$ yr^{-1}. It is shown that the Bondi-Hoyle process responsible for the accretion of $\sim10^{22}$ g s^{-1} by Sgr A* also produces a downstream, focused flow with a radius very similar to that of the mini-cavity and a mechanical luminosity about 2.5 larger than L_{cav}. In addition, the size and density of the blobs appear to be consistent with the gas characteristics in this flow.

2.7 Gamma-Ray Astrophysics

The Compton Gamma Ray Observatory was launched April 4, 1991. The CGRO/OSSE experiment (Jim Kurfess, NRL, PI) in which NU (Ulmer, Co-Investigator) has participated is working well and has already made detections of nearly all the major prelaunch objectives: the Galactic center/plane emission of 0.5 MeV, AGNs, the Crab nebula and pulsar, binary X-ray sources, black hole candidates, gamma-ray bursts, and solar flares. The analysis at NU is being performed by Grabelsky (who left the group Nov. 1, 1996), Matz, Purcell, and Ulmer. Matz is chairman of the OSSE gamma-ray burst team, Purcell is chairman of the OSSE diffuse Galactic emission team. Ulmer is chairman of the OSSE pulsar team and the GRO pulsar committee. Most of the observations agree with prelaunch expectations. We have begun a search for transient sources of line and continuum emission in these data.

We have also detected the ^{26}Al line from the Galactic plane. We are currently developing a technique of using earth occultations to improve our sensitivity to ^{26}Al. Preliminary results indicate a factor of 3 improvement in sensitivity is possible. This improvement will allow us to measure the distribution of ^{26}Al in the galactic plane on scales of $\sim$ 30 degrees.

In collaboration with James Cordes and Zaven Arzoumanian (Cornell Univ.), they have been using OSSE to study pulsars. They have now made a survey of 15 pulsars including several milli-second pulsars. They have set upper limits to these. In some cases these limits are significantly below the predicted trends based on the relationship between the luminosity of gamma-ray detected pulsars and other properties of the pulsars such as spin-down rate. They have also analyzed the observations of the Crab pulsar over a 5-year period, and they find no evidence for variability in intensity or in the ratio of the peaks of the light curve. They have also done a deep search for line emission in the 400–600 keV range, and they have found no evidence for any lines.

Purcell has worked with David Dixon (Univ. of California, Riverside) Marvin Leventhal (Univ. of Maryland), and Lingxiang Cheng (Univ. of Maryland). They have developed techniques for generating maps of gamma-ray emission using OSSE observations of the Galactic plane and Galactic Center region. These techniques have been used to generate the first-ever maps of the Galactic 511 keV positron annihilation line. These maps show evidence for a central Galactic bulge and a weak Galactic disk. The weak disk flux is consistent with that expected from positrons produced by radioactive ^{26}Al in the interstellar medium. In addition to the bulge and disk features, maps of the 511 keV line emission also show evidence for a feature near $l=-4°$, $b=+7°$ with a flux about 50% that of the bulge. The source of this enhanced emission is unknown. A series of OSSE observations have been scheduled for late 1996 which will provide additional information covering a region $\sim25°\times25°$ around the galactic center. These observations will help to improve our knowledge of the source and distribution of the 511 keV annihilation radiation.

Work has continued in the analysis of the simultaneous OSSE and GRANAT/Sigma observations of the Galactic center region. By combining the high sensitivity OSSE data with the imaging Sigma data, it has been possible to remove the known point source contributions from the OSSE data, providing an estimate of the diffuse Galactic gamma-ray continuum in the energy range 50 keV – 1 MeV. The observed emission is found to be broad and nearly flat in galactic longitude over the range $+25°<l<-20°$. Analysis of the spectrum suggests that the emission turns up below a few hundred keV. If the observed emission is due to cosmic-ray electron interactions in the interstellar medium, this would indicate that the spectrum of low energy cosmic-ray electrons extends down to much lower energies than previously thought, and that these electrons represent a significant fraction of the heating of the interstellar medium. Alternatively, the observed spectrum may be the result of multiple unresolved X-ray sources below the Sigma detection threshold. If this is the case, then approximately 1 such source/degree of longitude would be required to explain the observed spectrum.

NU is the center for OSSE burst analysis. Matz maintains the OSSE burst data archive online at: http://www.astro.nwu.edu/astro/osse/bursts. New results are published monthly. This is by far the most up-to-date publicly available database of gamma-ray bursts. It has been used to spark research, including a collaboration with COMPTEL to test the cosmological origin of bursts. The site has had tens of thousands of total accesses to date from more than 1000 sites around the world.

Recent burst analysis with OSSE has focused on the search for pre- and post-burst emission from burst sources. The BATSE/OSSE burst response system allows OSSE to observe burst sources within 100 s of their detection. This has been approved and funded as a GRO guest investigator observation in the last three NASA reviews. In addition, extensive studies of serendipitous OSSE observations of burst locations before and after events have been made.

The OSSE observations cover a number of time scales before and after bursts, including immediately before (when, in a NS-NS or NS-BH scenario, there should be significant tidal heating and neutrino emission) and after (when NS remnants/disk may be consumed). Being so close to the event, and in the energy range of primary interest, these observations may put significant constraints on models. The observations on longer time scales may also be of interest in themselves, and they provide an important baseline for the close-in measurements. Results from several events indicate that the average low-energy flux immediately before and after a burst must be less than 2% of the average burst flux. No other instrument can make as sensitive observations of burst sources in this energy range.

Matz is also a co-investigator (with Gerry Share of NRL as PI) on NASA ADP funded work to produce a final catalog of the >100 strong gamma-ray bursts observed by the Gamma-Ray Spectrometer on the Solar Maximum Mission satellite. This may provide the best available data set for the study of high-energy (>1 MeV) emission in gamma-ray bursts.

A new OSSE observation of the pulsar PSR B1509$-$58 with Matz as PI was approved and funded in the last set of GRO guest investigator proposals. It is a three-week observation scheduled to be carried out in May 1997, with the dual goals of 1) making a better observation of the low-energy pulsar spectrum to determine the spectral break energy and 2) measuring the diffuse nebular hard X-ray emission. This will help test models of plerion emission and constrain the energetic electron spectrum and ambient magnetic field. They will also improve constraints on the high-energy cut off, a test of polar cap models.

2.8 Globular Cluster Observations

With M. Bolte (UCSC), P.B. Stetson, and J.E. Hesser (DAO/HIA), E. Sandquist has reduced and studied photometry of over 40,000 stars in the Galactic globular cluster M5. The luminosity functions for the cluster have been computed from the tip of the red giant branch to several magnitudes below the main-sequence turnoff. The ''red-giant bump'' has been detected in the photometry, and its anomalous magnitude relative to oxygen-enhanced stellar models can potentially be explained by α-element enhancements observed in the cluster. This result is important because it would remove the need to invoke convective overshooting as has been traditionally done for other clusters. The helium abundance of the cluster as determined from the population ratio $R=N_{HB}/N_{RGB}$ is found to be $Y=0.19\pm0.02$. No other evidence of low helium abundance is found, however, leading them to conclude that the stellar populations have been affected in some way. Using an improved subdwarf fit to the main sequence of the cluster to derive the distance modulus, an absolute age of 13.5 Gyr ±1 Gyr (internal error) is found for the cluster. More importantly though, the relative age difference between M5 and the cluster NGC 288 is found to be 3.5 Gyr $\pm$ 1.5 Gyr, as errors in chemical composition values do not appear to be capable of explaining the large apparent difference in magnitude between the horizontal branch and the main sequence turnoff.

2.9 Hydrodynamics

In collaboration with M. Bolte and L. Hernquist (UCSC), Sandquist has carried out hydrodynamic and hydrostatic simulations of blue straggler formation mechanisms (direct collisions and binary mergers). Smooth-particle hydrodynamical simulations of the merger of two main-sequence stars have in all cases indicated that there is very little mixing of core material for the two stars into the envelope of the remnant star. As a result, helium that has been created by hydrogen burning in the progenitor stars remains in the core of the remnant, considerably shortening the core hydrogen-burning phase of its evolution. In addition, it is found that very little additional mixing of core material into the envelope occurs during the hydrostatic relaxation of the remnant star or during the subsequent main sequence evolution. With or without mixing, the remnant stars spend a large fraction of their time near the main sequence. This result implies that current models are unable to explain the color distribution seen in the photometry of blue stragglers in Galactic globular clusters.

2.10 Interstellar Medium

In collaboration with M. Jura (UCLA) and the late J. A. Cardelli (Villanova), Meyer has obtained high signal-to-noise *HST* Goddard High Resolution Spectrograph (GHRS) echelle observations of the weak interstellar O I] λ1356 absorption toward the stars γ Cas, ϵ Per, δ Ori, ϵ Ori, 15 Mon, τ CMa, and γ Ara. In combination with previous GHRS measurements in six other sightlines, these new observations yield a mean interstellar gas-phase oxygen abundance (per 10^6 H atoms) of 10^6 O/H $=316\pm9$. There are no statistically significant variations in the measured O abundances from sightline to sightline and no evidence of density-dependent O depletion from the gas phase. Assuming various dust mixtures of oxides and silicates such as olivine, the abundance of interstellar O tied up in dust grains is unlikely to surpass 10^6 O/H ≈180. It is difficult to further increase this O fraction in grain cores simply because the requisite metals are far less abundant than oxygen. Consequently, the GHRS observations imply that the *total* abundance of interstellar oxygen (gas plus grains) in the vicinity of the Sun is about 2/3 of the solar value of 10^6 O/H $=741\pm130$.

Cardelli, Meyer, Jura, and B. D. Savage (U. Wisconsin) have also used the GHRS to analyze the abundance of interstellar carbon from high S/N echelle observations of the weak C II] λ2325 intersystem transition in six sightlines. They find that the interstellar gas-phase C abundance shows no dependence on either direction or the physical condition of the gas, and that 10^6 C/H $=140\pm20$. If, like oxygen, the *total* abundance of interstellar carbon is 2/3 of the solar value (10^6 C/H $=355\pm43$), the GHRS observations imply an amount of C in grains (10^6 C/H ≈100) that would tightly constrain extinction models. For example, this amount of solid carbon can explain such extinction features as the 2175 Å bump through graphite and/or PAHs but would put severe restrictions on the availability of carbon in grains to explain the total optical/UV dust opacity.

J. K. Watson (NU graduate student) and Meyer have obtained high resolution ($\Delta v \approx 1.4$ km s^{-1}) observations of the interstellar Na I absorption toward the members of 17 binary star systems with the KPNO 0.9 m Coude Feed telescope and spectrograph. These binaries consist of stars ranging in spectral type from O6 to A5, lie at distances between 85 and 1200 pc, and have stellar separations ranging between 480 and 29,000 AU@. The rather definitive result is that *all* of these systems exhibit variations in their interstellar Na I line profiles. Individual velocity components often change in strength, occasionally disappear entirely, and sometimes appear to shift in velocity. Thus, it appears that small-scale structure in the cold atomic gas is truly pervasive in the diffuse interstellar medium.

2.11 Numerical relativity

Finn is co-Investigator on the NSF computational Grand Challenge project ''Black Hole Binaries: Coalescence and Gravitational Radiation.'' The goal of this project (which also involves the University of Texas at Austin, University of Illinois at Urbana, University of North Carolina, Cornell University, Pittsburgh University, Pennsylvania State University, and Syracuse University) is to solve numerically for the evolution of and gravitational radiation from the coalescence of two black holes.

Since its inception, the practice of numerical relativity has been dominated by finite difference methods. The reasons for this are primarily historical: (1) The field equations of relativity are highly non-linear and (when numerical relativity was in its infancy) the treatment of nonlinearities by spectral techniques was very difficult while their treatment by finite difference techniques was very straightforward; (2) Early numerical relativists drew upon the expertise developed at the national laboratories for solving the similarly non-linear equations of hydrodynamics, and this expertise was primarily in finite differencing.

In the intervening years, spectral methods have undergone considerable development, and there is no longer any *a priori* reason that numerical relativity should be practiced exclusively with finite difference methods. In collaboration with post-doc Larry Kidder, Finn has investigated the use of spectral techniques for numerical relativity calculations.

Also in collaboration with Kidder, Finn is studying ways of characterizing initial data sets for numerical relativity calculations.

2.12 Sources of gravitational radiation

In anticipation of the operation of large and sensitive gravitational wave detectors (e.g., the Laser Interferometer Gravitational-wave Observatory (LIGO) and VIRGO detectors) Finn has become increasingly involved in developing tools for gravitational-wave data analysis involving single detectors as well as multiple instruments operated as a single, networked detector. He is just now completing a large study of signal detection and measurement, for either deterministic or stochastic gravitational-wave signals, using a general ''detector'' consisting of multiple instruments at arbitrary geographical locations.

Plans are currently being studied to develop a large acoustic gravitational-wave detector. In support of those plans, Finn has recently published an overview of gravitational-wave sources that such a detector might observe.

2.13 Submillimeter Polarimetry

G. Novak, J. Dotson, and graduate student T. Renbarger are building a Helium-3 cooled 9-pixel submillimeter polarimeter for use with the 2-meter Viper telescope at the South Pole. This instrument, called SPARO (the Submillimeter Polarimeter for Antarctic Remote Observations), will be used to observe the Galactic Center during the Austral Winter of 1998, in collaboration with investigators from the University of Chicago and Carnegie Mellon University (Novak, Platt, & Dragovan 1995; Novak *et al.* 1995). The technique of submillimeter polarimetry has been developed over the last decade, and is used for mapping magnetic fields in highly obscured regions of the interstellar medium. The goal of the SPARO observations is to discover the large-scale configuration of the magnetic field in the center of the Galaxy. Specific questions that will be addressed include:

What is the configuration of the magnetic field in the material that surrounds the circumnuclear ring? The role of magnetic fields in astrophysical accretion disks has been the topic of a large body of theoretical work. At last we have a case where we can observe the magnetic field inside an accretion disk: the 3-pc circumnuclear disk in Sgr A. So far, the characteristics of the polarized far-IR emission from the disk appear to be consistent with the predictions of the magnetic accretion disk model developed by Blandford and Payne. An important test of the model is to observe the field at points surrounding the disk. This will be done with SPARO.

What is the relationship between the magnetic field in the hot, ionized regions and that in the cooler, neutral regions? One of the mysteries that is associated with the Galactic Center is the nature of the bright, straight, non-thermal radio filaments that have been discovered at several locations within the central 100 pc. It has been argued that these filaments are evidence for a strong poloidal Galactic Center magnetic field. The planned South Pole observations will determine the extent to which this poloidal field penetrates into the neutral regions.

SPARO is the first sub-Kelvin submillimeter detector system that will be used in Antarctica during the winter. The design of the cryostat incorporates several features that will simplify its operation and servicing. The parts for the Helium-4 cryostat have been built, and first tests of this component will take place in Fall 1996. The completed instrument is scheduled to be tested with the Viper telescope at Carnegie Mellon University in Summer 1997.

2.14 X-ray Detectors

J. Ketterson, S. Maglic, and C. Thomas (Department of Physics and Astronomy) have been working, with input from Ulmer, on the development of a superconducting tunnel junction (STJ) as an X-ray detector. The detectors are being entirely fabricated in-house. The multilayer tunnel junction design allows them to overcome many of the problems encountered in single layer junctions, including such obvious effects as the thickness of the detector (single layer junctions are too thin to effectively absorb photons at energies near 7 keV). They are planning expansion into 3 areas:

The use of AlN rather than Al_xO_y as the insulating layer. This allows for ease in fabrication and flexibility in the thickness of the insulating layer.

The use of tunnel junctions as visible light detectors that will also provide energy resolution.

The development of a resonant cavity detector whose ''Q'' is dependent on the surface conductivity. This should be linearly dependent on the energy of absorbed photons which will produce quasi-particles that will migrate to the surface of the cavity. This design has two advantages over ordinary STJs:

The thickness of the absorbing layer can be made at least 10 times thicker.

Tunneling is not required. They plan to fabricate and test a device. If the primary reason that STJs have not been able to achieve near-theoretical resolution is that the quasi-particles do not tunnel efficiently, then the resonant cavity will perform much better (a factor of ~ 10 better energy resolution) than the standard STJs. If, however, the reason for poor resolution in the STJ is due to the trapping and recombining of quasiparticles in two superconducting lattices, then we will be able to demonstrate this with similar performance in the resonant cavity design.

2.15 X-ray Mirror Technology

Ulmer along with R. Altkorn (in the Northwestern University Basic Industry Research Laboratory) has continued the development of the fabrication of X-ray mirrors via replication. They have produced flats that are better than 3Å smooth. They have just been awarded 3 grants from NASA to study X-ray mirror fabrication. Two of the projects are specifically for the purpose of making mirrors that function in the about 40–100 keV range. The other project is to perfect high-angular-resolution, small, light-weight mirrors for studying the sun in the $\sim 1-10$ keV range. All of these projects are in collaboration with Dr. Allen Krieger of Radiation Science, Inc. In collaboration with Prof. Yip-Wah Chung and Drs. William Sproul and Ming-Show Wang, they are investigating the use of super hard coating. The coating not only protects the master they use in the electroforming process but also smooths the surface. Preliminary tests indicate that the super hard coating will be of benefit. They plan to make their first X-ray tests at the Advanced Photon Source (APS) at Argonne National Laboratory in December of 1996. These tests will be done in collaboration with APS employees Drs. Barry Lai and Derrick Mancini.

2.16 X-ray Shadows

Q. Daniel Wang and collaborators are currently carrying out an extensive *ROSAT* archival study of X-ray shadows produced by many X-ray-absorbing gas clouds (e.g., IR Cirrus). They have published a sample of five fields they have examined. They have successfully obtained telescope time at both Kitt Peak and CTIO for follow-up optical observations to measure the distances of clouds.

In one particular field near the Large Magellanic Cloud, they have carefully examined the extent, pervasiveness, and emission color of the local hot gas. They have analyzed the X-ray shadows cast by two interstellar clouds, adjacent in the sky, but at different distances ($D \sim 70$ pc, and 160 pc, respectively). X-ray absorption by diffuse cool gas is tightly constrained by observations of EUV sources in the field. They find that the X-ray-emitting gas does *pervade* between the clouds, based on the rough proportionality of emission intensity to cloud distance. From the measured X-ray emission intensity and color, they infer that the average temperature and density in the sightline to the nearer cloud as $\sim 10^6$ K and $0.005 cm^{-3}$, assuming an optically-thin thermal model. But the emission colors are significantly different in the two sightlines, indicating that the hot gas temperature varies in space. The temperature between the clouds is probably only $\sim 6 \times 10^5$ K. These findings, together with previous X-ray shadow observations, suggest that the Sun is indeed located in a low-density, hot superbubble, and that a part of this superbubble has been recently heated by a break-out from an even hotter ($\sim 2.4 \times 10^6$ K) superbubble centered around the Scorpius-Centaurus starburst region. Much of the Galactic 0.1 – 1 keV background can be explained by the emission from these two superbubbles and their interaction.

3. EDUCATIONAL PROGRAM

The Summer Research Program for High School Students and Undergraduates continues. This is funded primarily by a NASA educational grant. We had a very successful summer program which enabled students to gain research experience. This past summer we had five high school students and ten undergraduates working individually on research projects with professors and postdoctoral fellows. Seminars were held once a week and the last two weeks concluded with the students making their own presentations about their research projects.

PUBLICATIONS

Cardelli, J.A., Meyer, D.M., Jura, M., & Savage, B.D. 1996, ''The Abundance of Interstellar Carbon,'' *Ap. J.*, **467**, 334.

Chen, X., & Taam, R.E. 1996, ''The Spectral States of Black Hole X-Ray Binary Sources,'' *Ap. J.*, **466**, 404.

Cruddace, R.G., Fenimore, E.E., Fritz, G.G., Kowalski, M.P., Snyder, W.A., and Ulmer, M.P. 1997, ''The Baryon Fraction in the Perseus Cluster: Results from Spartan 1,'' to be published in *Ap. J.*

Dowell, C.D., Hildebrand, R.H., Schleuning, D., Dotson, J.L., & Novak, G. 1996, '' Far-Infrared Polarization by Absorption in the Molecular Cloud Sagittarius B2,'' submitted to *Ap. J.*

Finn, L.S. 1995, ''Binary Neutron Star Inspiral, LIGO, and Cosmology,'' *Seventeenth Texas Symposium on Relativistic Astrophysics and Cosmology*, eds. H. Böhringer, G.E. Morfill, & J.E. Trumper, Ann. N.Y. Acad. Sci., **759**, 489.

Finn, L.S. 1996, ''Binary Inspiral, Gravitational Radiation, and Cosmology,'' *Phys. Rev. D*, **53**, 2878.

Finn, L.S. 1996, ''A Numerical Approach to Binary Black Hole Coalescence,'' to appear in *The Proceedings of the 14th International Conference on General Relativity and Gravitation* .

Finn, L.S. 1996, ''Cosmology and LIGO,'' to appear in *Neutrino Mass, Monopole Condensation, Dark Matter, and Gravitational Waves* (Plenum Press).

Finn, L.S. 1996, ''Data analysis with multiple data streams,'' *Aspen Winter Conference on Gravitational Waves and Their Detection*, ed. S. Meshkov (Aspen, Colorado: Aspen Center for Physics).

Finn, L.S. 1996, ''Gravitational radiation sources for acoustic detectors,'' to appear in the proceedings of *OMNI-1: The First International Workshop for an Omnidirectional Gravitational Radiation Observatory*.

Finn, L.S. 1996, ''Gravitational-wave astronomy,'' to appear in the proceedings of *ICGC-95: The International Conference for Gravitation and Cosmology*.

Grabelsky, D.A., Matz, S.M., Purcell, W.R., Ulmer, M.P., Finley, J.P., Wilson, R.B., Pendleton, G.N., & Cordes, J.M. 1996, ''High Rate Telemetry as a Novel Approach to Opening New Vistas of High-Energy Astrophysics,'' *Gamma Ray and Cosmic Ray Detectors, Techniques and Missions*, to be published by SPIE.

Grossman, S.A., & Taam, R.E. 1996, ''Double Diffusive Mixing Length Theory, Semiconvection, and Massive Star Evolution,'' *MNRAS*, in press.

Kunz, M., Kendziorra, E., Kretschmar, P., Maisack, M., Staubert, R., Ulmer, M.P., Kurfess, J.D., & Wilson, R.B. 1996, ''OSSE Observations of Her X−1 during the Main-On State,'' to be published in *A &A*.

Lundgren, S.C., Cordes, J.M., Ulmer, M.P., Matz, S.M., Lomatch, S., Foster, R.S., & Hankins, T. 1995, ''Giant Pulses from the Crab Pulsar: A Joint Radio and Gamma-Ray Study,'' *Ap. J.*, **453**, 433.

Matz, S.M., Grove, J.E., Johnson, W.N., Kurfess, J.D., & Share, G.H. 1995, ''OSSE Limits on Pre- and Post-Burst Emission,'' *Ap&SS*, **231**, 123.

Matz, S.M., Fender, R.P., Bell Burnell, S.J., Grove, J.E., & Strickman, M.S. 1996, ''Hard X-ray and IR observations of Cygnus X-3'' *A&A*, in press.

Matz, S.M., Grove, J.E., Johnson, W.N., Kurfess, J.D., Share, G.H., Fishman, G.J., & Meegan, C. A. 1995,''BATSE/OSSE Rapid Burst Response,'' *Ap&SS*, **231**, 127.

Matz, S.M., Grabelsky, D.A., Purcell, W.R., Ulmer, M.P., Pendleton, G.N., Cordes, J.M., Finley, J.P., Wheaton, W.A., & Wilson, R.B. 1996,''ALLEGRO: A New Approach to Gamma Ray Bursts,'' *Third Huntsville Gamma-Ray Burst Workshop*, ed. C. Kouveliotou, M.S. Briggs, & G.J. Fishman (New York: AIP), in press.

Matz, S.M., Grove, J.E., Johnson, W.N., & Share, G.H. 1996, ''OSSE Limits on Pre- and Post-Burst Emission from GRB950421,'' *Third Huntsville Gamma-Ray Burst Workshop*, ed. C. Kouveliotou, M.S. Briggs, and G.J. Fishman (New York: AIP), in press.

Matz, S.M., Meegan, C.A., Fishman, G.J., Grove, J.E., Johnson, W.N., & Share, G.H. 1996, ''Recent Results from the BATSE/OSSE Rapid Burst Response,'' *Third Huntsville Gamma-Ray Burst Workshop*, ed. C. Kouveliotou, M.S. Briggs, & G.J. Fishman (New York: AIP), in press.

Melia, F., Coker, R. F., & Yusef-Zadeh, F. 1996, ''A Hydrodynamical Model for the Formation of the Galactic Center ''Mini-cavity,'''' *ApJ*, **460**, L33.

Meyer, D. M. 1996, ''Optical and Ultraviolet Observations of Diffuse Interstellar Clouds,'' *Molecules in Astrophysics*, ed. E. F. van Dishoeck (Dordrecht: Kluwer), IAU Symposium No. **178**, in press.

Meyer, D. M., & Blades, J. C. 1996, ''Small-Scale ISM Structure: The Remarkable Sight Line Toward μ Crucis,'' *Ap. J.*, **464**, L179.

Miller, G.S., & Park, M.-G. 1995, ''Oscillatory Modes in Near-Critical Accretion Flows,'' *Ap. J.*, **440**, 771.

Miller, G.S. 1996, ''Shrill Notes from the Stars,'' *Nature*, **381**, 472.

Miller, G.S. 1996, ''The Accretion Curtain and Pulse Phase Variations of the Bursting X-ray Pulsar GRO 1744-28,'' *Ap. J.*, **468**, L29.

Miller, G.S., & Grossman, S. 1997, ''Temporal Variability in Radiation-driven Outflows,'' in preparation.

Miller, G.S., & Park, M.-G. 1997, ''Stability and Variability in Near-Critical Accretion Flows: General Relativistic Treatment,'' in preparation.

Milsom, J. A., & Taam, R.E. 1996, ''Variability of Black Hole Accretion Disks: Effects of Local and Global Inertial-Acoustic Oscillations,'' *MNRAS*, in press.

Nichol, R.C., Holden, B.P., Romer, A.K., Ulmer, M.P., Burke, D.J., & Collins, C.A. 1996, ''Evolution in the X-Ray Cluster Luminosity Function Revisited,'' submitted to *Ap. J.*

Novak, G., & Jarrett, T. 1995, ''A Technique for Accurate Stellar Polarimetry using CCD Cameras,'' *Applied Optics*, **34**, 1672.

Novak, G., Dotson, J.L., Dowell, C.D., Hildebrand, R.H., Platt, S.R., Schleuning, D., & Goldsmith, P.F. 1996, ''Polarization of the Lambda = 115 m Radiation from Sagittarius B2,'' submitted to *Ap. J.*

Phlips, B.F., Jung, G.V., Leising, M.D., Grove, J.E., Johnson, W.N., Kinzer, R.L., Kroeger, R.A., Kurfess, J.D., Strickman, M.S., Grabelsky, D.A., Matz, S.M., Purcell, W.R., Ulmer, M.P., & McNaron-Brown, K. 1996, ''Gamma Ray Observations of Cygnus X−1 with the Oriented Scintillation Spectrometer Experiment,'' *Ap. J.*, **465**, 907.

Psaltis, D., Lamb, F.K., & Miller, G.S. 1995, ''X-ray Spectra of Z-sources,'' *Ap. J.* , **454**, L137.

Rippert, E.D., Song, S.N., Thomas, C.D., Lomatch, S., Maglic, S.R., Ulmer, M.P., & Ketterson, J.B. 1995, ''Intrinsically Damped Multilayered (Stacked) Nb/Al-AlN$_x$/Nb Superconducting Tunnel Junctions,'' *Applied Superconductivity*, **3**, 567.

Roberts, D.A., Yusef-Zadeh, F. & Goss, W.M. 1996, ''Kinematics of Ionized Gas in Sgr A West: The Minicavity and the Western Arc,'' *The Galactic Center:*, ed. R. Gredel, ASP Conference Series, **102**, 137.

Roberts, D.A., Yusef-Zadeh, F., & Goss, W.M. 1996, ''Kinematics of the Ionized Gas in Sgr A West: Mass Estimates of the Inner 0.13 pc of the Galaxy,'' *ApJ*, **459**, 627.

Sandquist, E.L., Bolte, M., and Stetson, P.B. 1996, ''The Composition and Stellar Populations of M5,'' in *Formation of the Galactic Halo . . . Inside and Out*, ed. H. Morrison and A. Sarajedini (San Francisco: ASP), 293.

Sandquist, E.L., Bolte, M., Stetson, P.B., and Hesser, J.E. 1996, ''CCD Photometry of the Globular Cluster M5. I. The Color-Magnitude Diagram & Luminosity Functions,'' *Ap. J.*, **470**, 910.

Sandquist, E.L., Bolte, M., & Hernquist, L. 1997, ''Composition Mixing during Blue Straggler Formation and Evolution,'' *Ap. J.*, in press.

Schleuning, D., Dowell, C.D., Platt, S.R., Hildebrand, R.H., & Novak, G. 1996, ''Hertz: A Submillimeter Polarimeter,'' *Pub. Astron. Soc. Pacific*, in press.

Song, S.N., Maglic, S.R., Thomas, C.D., Rippert, E.D., Auvil, P.R., Ulmer, M.P., & Ketterson, J.B. 1996, ''Studies of Static and Dynamic Properties of Multilayered (Stacked) Josephson Junctions,'' *Oxide Superconductors: Physics and Nano-Engineering II*, Proc. SPIE **2697**, 487.

Song, S.N., Maglic, S.R., Thomas, C.D., Ulmer, M.P., & Ketterson, J.B. 1996, ''High Energy Resolution X-Ray Detection Based on a Coupled Fiske Cavity and Josephson Junction Oscillator,'' *Appl. Phys. Lett.*, **69**, 1631.

Song, S.N., Thomas, C.D., Rippert, E.D., Maglic, S.R., Song, Y.C., Lin, S.W., Lin, C.T., Ulmer, M.P., & Ketterson, J.B. 1996, ''Evidence for Collectively Phase-locked Shapiro Steps in Stacked Nb/Al-AlO_x/Nb Josephson Junctions,'' *Physics Letters A*, **211**, 172.

Staguhn, J., Stutski, J., Yusef-Zadeh, F., & Uchida, K.I. 1996, ''The Interaction of the G359.54+0.18 Nonthermal Filaments with the Ambient Medium,'' *The Galactic Center*, ed. R. Gredel, ASP Conference Series, **102**, 447.

Strickman, M.S., Grove, J.E., Johnson, W.N., Kinzer, R.L., Kroeger, R.A., Kurfess, J.D., Grabelsky, D.A., Matz, S.M., Purcell, W.R., Ulmer, M.P., & Jung, G.V. 1996, ''OSSE Observations of the Vela and Geminga Pulsars,'' *Ap. J.*, **460**, 735.

Strickman, M.S., Dermer, C.D., Grove, J.E., Johnson, W.N., Jung, G.V., Kurfess, J.D., Phlips, B.F., Share, G.H., Sturner, S.J., Messina, D.C., & Matz, S.M. 1996,''Hard X-Ray Spectroscopy and Pulsar Phase Analysis of the Bursting X-Ray Pulsar GRO J1744-28 with OSSE,'' *Ap. J.*, **464**, L131.

Taam, R.E. 1996, ''Common Envelope Evolution, the Formation of CVs, LMXBs, and the Fate of HMXBs,'' *Compact Objects in Binaries*, ed. J. van Paradijs, E. P. J. van den Heuvel, & E. Kuulkers (Kluwer: Dordrecht), IAU Symposium No. **165**, 3.

Taam, R.E., Woosley, S.E., & Lamb, D.Q. 1996, ''The Effect of Deep Hydrogen Burning in the Accreted Envelope of a Neutron Star on the Properties of X-ray Bursts,'' *Ap. J.*, **459**, 271.

Taam, R.E. 1996, ''Time Variabilities and Disk Instabilities,'' in *Basic Physics of Accretion Disks*, ed. S. Kato *et al.* (Gordon and Breach), in press.

Taam, R.E. 1996, ''Quasi-Periodic Oscillations in Black Hole Candidates,'' in *Theories and Observations of Compact Objects*, ed. G. J. Qiao, in press.

Taam, R.E. 1996, ''The Theory of X-Ray Bursts'' in *Theories and Observations of Compact Objects*, ed. G. J. Qiao, in press.

Tavani, M., Hermsen, W., van Dijk, R., Strickman, M.S., Zhang, S.N., Foster, R.S., Ray, P.S., Mattox, J., Ulmer, M.P., Purcell, W.R., & Coe, M. 1996, ''Monitoring the Gamma-Ray Source 2CG 135+1 and the Radio Star LSI +61° 303,'' to be published in *A&A*.

Terman, J.L., Taam, R.E., & Savage, C.O. 1996, ''A Population Synthesis Study of Low Mass X-Ray Binary Systems,'' *MNRAS*, **281**, 552.

Terman, J.L., & Taam, R.E. 1996, ''Double Core Evolution IX. The Infall of a Main Sequence Star Through the Envelope of an Intermediate Mass Red Giant Branch Companion,'' *Ap. J.*, **458**, 692.

Ulmer, M.P., Bernstein, G.M., Martin, D.R., Nichol, R.C., Pendleton, J.L., and Tyson, J.A. 1996, ''Low Surface Brightness Galaxies in the Core of the Coma Cluster,'' to be published by *AJ*.

Ulmer, M.P., Grabelsky, D.A., Purcell, W.R., Matz, S.M., Grove, J.E., Johnson, W.N., Kinzer, R.L., Kurfess, J.D., Strickman, M.S., & Jung, G.V. 1997, ''OSSE Monitoring of the Galactic Center Region,'' presented at the Second INTEGRAL workshop, to be published by ESTEC.

Wang, Q. D. 1996, ''X-ray Shadows of Infrared Cirrus and the Local Hot Interstellar Medium,'' *BAAS*, **187**, 1506.

Wang, Q. D., & Yu, K. 1995, ''Shadowing the Soft X-ray Background by Infrared Cirrus: A Study of Selected Regions,'' *A.J.*, **102**, 698.

Watson, J.K., & Meyer, D.M. 1996, ''Observations of Ubiquitous Small Scale Structure in the Diffuse ISM,'' *Ap. J.*, **473**, in press.

Yusef-Zadeh, F., Wardle, M. and Roberts, D. 1995, ''Detection of Ionized Gas Toward an OH/IR Star: A Measure of the UV Radiation Field Near the Galactic Center,'' *Ap. J.*, **458**, L21.

Yusef-Zadeh, F., Uchida, K.I. & Roberts, D. 1995, ''Shock Excited OH Maser Emission Outlining the Galactic Center Supernova Remnant/Supershell G359.1-0.05,'' *Science*, **270**, 1801.

Yusef-Zadeh, F., Parastaran, P. & Wardle, M. 1996, ''The Nature of the Scattering and Faraday Screens Toward the Galactic center,'' in *Unsolved Problems in the Milky Way*, ed. L. Blitz & P. Teuben (Kluwer), 271.

Yusef-Zadeh, F., Roberts, D.A., Goss, W.M., Frail, D.A. & Green, A.J. 1996, ''Detection of 1720 MHz Hydroxyl Masers at the Galactic Center: Evidence for Shock-Excited Gas and MilliGauss Fields,'' *Ap. J*, **466**, L25.

Yusef-Zadeh, F., Robinson, B.T., Roberts, D.A., Goss, W.M., Frail, D.A. & Green, A.J. 1996, ''The 1720 Mhz

OH Emission from G359.1-0.5 and the CND,'' *The Galactic Center*, ed. R. Gredel, ASP Conference Series, **102**, 151.

Yusef-Zadeh, F., Roberts, D.A., Wardle, M. & Lee, H.-Y. 1996, ''A Measure of the Ionizing Radiation Field Near the Galactic Center'' in *Radio Emission from the Stars and the Sun*, ed. A.R. Taylor & J.M. Paredes (Kluwer), 65.

Yusef-Zadeh, F., Uchida, K.I., Nyman, L.-A., Casement, S. & Lindqvist, M. 1996, ''CS (J=2-1) Observations of the Sgr B Complex and FIR21,'' *The Galactic Center*, ed. R. Gredel, ASP Conference Series, **102**, 60.

Lee Samuel Finn
Steven M. Matz
David M. Meyer
Guy S. Miller
Giles Novak
William R. Purcell
A. Katherine Romer
Eric L. Sandquist
Ronald E. Taam
Melville P. Ulmer
Q. Daniel Wang
Farhad Yusef-Zadeh